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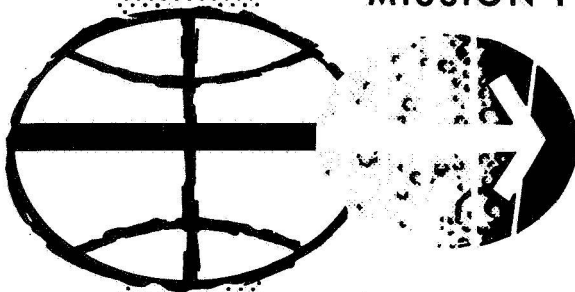
June 26, 1968

CHARACTERISTICS OF LM ABORTS WITH PGNCS DURING EARLY POWERED DESCENT

By J. D. Payne
Lunar Landing Branch

(This revision supersedes MSC Internal Note
67-FM-116 dated August 15, 1967.)

MISSION PLANNING AND ANALYSIS DIVISION



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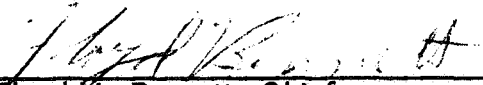
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PROJECT APOLLO
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DURING EARLY POWERED DESCENT

By J. D. Payne
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CHARACTERISTICS OF LM ABORTS WITH PGNC'S
DURING EARLY POWERED DESCENT

J. D. Payne

1.0 SUMMARY

Abort's in the early part of the LM powered descent have both a more difficult procedure and more difficult guidance requirements than abort's during the remainder of the powered descent. A study was made to define abort characteristics with the present PGNC'S onboard implementation (including recent changes) for abort's up to 200 seconds into the descent for the lunar landing mission. Procedures to eliminate the requirement to shut down the DPS abort's were investigated.

Results indicate that the present PGNC'S implementation is adequate for APS abort's. For DPS abort's the present implementation is adequate except for the requirement to shut down and reignite the DPS for abort's less than 50 seconds into the descent. It is not desirable to shut down an operating propulsion system in an abort situation. Two procedures to eliminate DPS shutdown were found. One uses DPS throttling to minimum thrust for the first 18 seconds of the abort burn. The second requires continuation of the DPS burn in the retrograde attitude, until the DPS burn time is 50 seconds, at which time steering toward the desired target conditions is initiated. Both procedures require a software change.

2.0 INTRODUCTION

This note describes the characteristics of LM abort's early during powered descent for the lunar landing mission. Included are the effects of the recent onboard program change (ref. 1) redefining the abort zones and implementing jerk limiting in the PGNC'S ascent guidance equations. The approach used is to define why there is a problem performing early LM abort's and then describe the rationale behind the development which led to the current implementation, which includes the requirement to shut down and reignite the DPS for early DPS abort's. The effects of varying the desired insertion velocity and using various guidance modes (including those currently implemented in the PGNC'S programs) are examined. The guidance modes considered in this study are position control,

no position control, and jerk limiting.

In addition to the different guidance modes, different procedures for operation of the propulsion systems for the abort are considered. For APS aborts, both aborts with delays in APS ignition in order for the LM to orient to the required attitude and aborts with no delay in APS ignition are considered. For DPS aborts, effects of leaving the DPS on at FTP (maximum thrust) and at minimum thrust as well as effects of DPS shutdown, orientation of the LM to the required abort attitude, and DPS reignition are considered. Various procedures to allow the DPS to remain in continuous operation for all DPS aborts are investigated. This note supersedes an earlier report (ref. 2) on early LM aborts.

3.0 ABBREVIATIONS

AGS	abort guidance system
APS	ascent propulsion subsystem
CSM	command and service modules
DPS	descent propulsion subsystem
FTP	fixed throttle point
GSOP	guidance system operations plan
K_R	ascent guidance constant
LM	lunar module
PGNCS	primary guidance and navigation control system
$\ddot{\ddot{R}}_D$	desired jerk (derivative of acceleration)
t_a	time of abort
t_{go}	time to go
θ	pitch angle
θ_β	pitch angle at insertion

4.0 THE PROBLEM OF EARLY LM ABORTS

In the nominal LM descent trajectory (ref. 3), powered descent is initiated at pericyynthion of a 50 000-ft by 60-n. mi. altitude orbit. The abort target conditions currently require that the LM be inserted into a standard orbit in the CSM orbital plane with pericynthion at 60 000-ft altitude. The target apocynthion altitude for aborts prior to high gate will probably be 60 n. mi. or higher.

Solution to the guidance problem for an early abort is difficult because the position error is large (in that at least 10 000 ft in altitude is to be gained) and the velocity error is small since the required insertion velocity is 5551 fps (for a 60 000-ft by 60-n. mi. orbit) and the LM velocity early in powered descent is also in this range, as can be seen from the LM inertial velocity profile in figure 1. The LM inertial velocity is greater than 5551 fps until about 8 seconds into the descent. Thus, not only is it difficult to achieve the desired insertion altitude of 60 000 ft, but also it is evident that some aborts during the trim phase result in retrograde burns because the current orbit has more energy than the desired orbit. The LM apocynthion altitude profile (also in fig. 1) indicates that the LM apocynthion altitude is about 39 n. mi. at the end of the 26-second trim phase. It is clear that if a minimum abort orbit of 50 000 ft by 39 n. mi. is acceptable for rendezvous (both LM-active and CSM-active), then one procedure for aborts during the trim phase would be a simple DPS shutdown. In addition to the fact that the LM position and velocity relative to the abort target conditions are undesirable for early LM aborts, the LM attitude is usually very far from the desired abort attitude. The results are periods of maximum turning rate during the early aborts.

In order to describe the undesirable effects of early aborts, consider the characteristics of aborts using the standard lunar ascent guidance with position control (so that both the desired insertion attitude and velocity is achieved). Insertion altitude and burnout attitude as a function of abort time are shown in figure 2. Insertion altitude is 60 000 ft except for abort times (t_a) < 60 seconds. Drastic changes in insertion attitude occur for t_a < 60 seconds. The combined effect indicates the the guidance does not achieve the required target conditions for $33 < t_a < 60$. The boundary at $t_a = 33$ seconds indicates a premature engine shutdown due to initiation of the engine shutdown timer when $t_{go} < 4$ seconds. PGNCs ascent guidance (refs. 3 and 4) causes the initiation of a special timer to shut down the propulsion system anytime $t_{go} < 4$ seconds no matter how t_{go} changes subsequently. Thus, any LM abort program

using the ascent guidance equations results in premature engine shutdown for $t_a < 33$ seconds if the insertion velocity is 5510 fps.

(The effects of increased insertion velocity upon premature engine shutdown are discussed in section 5.3.)

Abort attitude profiles for position control are shown in figure 3. These attitude profiles describe the pitch angle, θ , as a function of time. Pitch is measured in a local horizontal system such that $\theta = 0^\circ$ places the +X-body axis in the local horizontal plane in the posigrade direction (i.e., in the same direction as the velocity vector). $\theta = \pm 180^\circ$ defines the retrograde attitude. Except for $\theta = 0^\circ$ and $\pm 180^\circ$, positive θ 's indicate the +X-body axis is above the local horizontal plane. In figure 3 attitude profiles at abort times $t_a = 40, 70$, and 110 seconds are presented. For $t_a = 40$ seconds the profile is very undesirable. A period of maximum turning rate (10 deg/sec) is followed by a period of a constant vertical attitude ($\theta = 90^\circ$) in order to gain altitude. This period is followed by another period of maximum turning rate and a second constant attitude period, but this time at $\theta = -90^\circ$ instead of $+90^\circ$. These attitude profiles assume that the parameter K_R in the ascent guidance is unity. If $K_R < 1$, as is recommended in the GSOP (ref. 5), then the attitude hold shifts from $\theta = 90^\circ$ with $K_R = 1$ to $\theta = 75^\circ$ with $K_R = 0.97$ (ref. 6). Values of $K_R < 1$ allow a component of thrust to be maintained in the down-range direction. No particular advantage has been found for use of this capability for LM aborts.

As we have indicated, the desired insertion conditions for $t_a < 60$ seconds are not always achieved. The attitude profile for $t_a = 40$ seconds characterized by periods of maximum turning rate and constant attitude illustrate why this is true. For $t_a = 70$ seconds the attitude profile is improved. There are only two periods of maximum turning rate instead of three, as in the $t_a = 40$ -second case, and the period of constant vertical attitude ($\theta = 90^\circ$) is decreased. For aborts at $t_a = 110$ seconds, the period of attitude hold at $\theta = 90^\circ$ is eliminated, and there is only a relatively short period of maximum turning rate at the beginning of the abort. This attitude profile is a significant improvement as compared to that for aborts at $t_a = 70$ seconds.

If guidance with position control is required in order to achieve a specified altitude for early aborts near $t_a = 40$ seconds, it is clear that very undesirable abort profiles result. Even the achievement of the desired altitude is degraded. Furthermore, since thrusting time to go, t_{go} ,

is used to initiate propulsion shutdowns, the very early aborts ($t_a \approx 33$ seconds) cause premature engine shutdown because of the very small initial t_{go} .

5.0 DEVELOPMENT OF CURRENT PGNC'S IMPLEMENTATION

In order to avoid the problem of early aborts using the standard ascent guidance with position control, it was proposed in reference 2 that two changes be made for aborts less than 150 seconds into the descent. First, since the LM attitude is initially very far from the desired abort attitude, it was proposed that the DPS be shut down, and the LM be oriented to the desired attitude prior to either DPS reignition or staging and APS ignition. And second, it was proposed that position control be eliminated from the guidance so that only achievement of the desired insertion velocity was required. If position control were retained, the initial attitude desired for the very early aborts was vertical ($\theta = 90^\circ$) in order to gain altitude to achieve the 60 000-ft insertion altitude, and the attitude profiles were not improved. On the other hand, with no position control the desired attitude was posigrade near the local horizontal ($\theta = \pm 10^\circ$), and the attitude profiles during the abort burn were almost constant in inertial space. Insertion altitude and attitude profiles for aborts in early descent, where the abort burn is delayed in order for the LM to achieve the desired attitude and the guidance employs no position control, are shown in figure 4. In this case the insertion attitude is near the local horizontal, and there is no area where premature engine shutdown might occur because t_{go} always decreases with elapsed time.

The proposal outlined above was implemented in the preliminary lunar landing mission GSOP (ref. 5). The principal difficulty with this implementation was that for aborts near 150 seconds into the descent, if no position control was used in the guidance, the resulting insertion altitude could be near the safe orbit limit of 35 000 ft. Since PGNC'S (as implemented in luminary programs P70 or P71) targets to a fixed insertion velocity without regard to the resulting insertion altitude (ref. 4), the apocynthion of the insertion orbit can be affected. Figure 5 shows apocynthion altitude as a function of insertion (pericynthion) altitude for a constant insertion velocity. Note that low insertion altitudes result in low apocynthion altitudes. This feature of PGNC'S guidance can have a severe impact on the rendezvous problem, particularly if a LM rescue is required, since the CSM would be required to dwell in a very low orbit in order to improve LM and CSM phasing.

5.1 Rationale for Jerk Limiting in Guidance

In order to prevent low insertion altitudes resulting from aborts from powered descent, a third type of guidance, other than position control and no position control, was considered. In this guidance scheme a jerk limiting technique is used which determines the level of position control available by limiting the allowed range of the jerk term (i.e., derivative of acceleration) in the guidance. Jerk limiting bridges the gap between guidance with position control and guidance with no position control. For very early aborts (near $t_a = 50$ seconds) guidance with little position control is desirable to avoid undesirable attitude profiles during the abort. Later in the descent ($t_a > 150$ seconds) position control is required to assure that the resulting insertion altitude is greater than 50 000 ft. By limiting the jerk term allowed in the ascent guidance, little position control for early aborts ($t_a \approx 50$ seconds) results. For later aborts ($t_a > 150$ sec) the computed jerk never reaches the limit of -0.1 ft/sec^3 and complete position control is maintained. Figure 6 indicates the effect on abort insertion altitude and attitude for guidance with position control, no position control, and jerk limiting both with the current limits of $-0.1 < \ddot{R}_D < 0$ and with the limits of $-0.2 < \ddot{R}_D < 0$. The effect of increasing the negative jerk limit results in more position control.

The AGS uses a jerk limiting scheme with the limits of $-0.1 < \ddot{R}_D < 0$ (ref. 4). In order to make the current PGNCs implementation compatible with that of the AGS, the same jerk limits were used. Insertion conditions for jerk limiting, as in the current implementation, are shown in figure 7. These insertion conditions appear to be acceptable for $t_a > 50$ seconds. The insertion altitude increases from about 53 000 ft at $t_a = 50$ seconds to 60 000 ft at $t_a \approx 150$ seconds, and the insertion attitudes (θ_β) have the LM +X-body axis no more than -35° below the local horizontal. For t_a between the 4-second t_{go} limit at $t_a = 33$ seconds (assuming an insertion velocity of 5510 fps) and $t_a = 50$ seconds, the insertion attitude, θ_β , begins to decrease rapidly toward -90° . Typical abort profiles with jerk limiting guidance are shown in figure 8. Attitude profiles for $33 < t_a < 50$ seconds are shown in figure 9. It is questionable whether these profiles are acceptable because of the large negative attitude angles at insertion and the long periods of maximum turning rate.

Jerk limiting in the present PGNCs implementation does improve the abort attitude profiles compared to those resulting from position control. (See figures 3, 8, and 9.) Attitude hold periods at $\theta = 90^\circ$ (or -90°) are eliminated. For very early aborts ($33 < t_a < 50$ seconds) the profiles for jerk limiting behave like those obtained with no position control. For $t_a > 150$ -seconds, the profiles for jerk limiting behave like those for position control. (When jerk limiting is used, the parameter K_R should be unity.) Use of jerk limiting does not eliminate the 4-second t_{go} boundary at $t_a = 33$ seconds. Also jerk limiting does not eliminate the requirement to shut down the propulsion system and orient to the desired abort attitude prior to initiation of the abort burn for aborts earlier than $t_a = 50$ seconds since premature shutdowns due to small initial t_{go} are not eliminated and insertion attitude profiles for $t_a < 50$ seconds are not desirable. However, the low insertion altitudes are eliminated since guidance with no position control is required only for $t_a < 50$ seconds.

5.2 Characteristics of the Current PGNCs Implementation

The current PGNCs implementation for aborts from powered descent distinguishes the abort guidance and procedures in three abort zones. The first zone is for aborts occurring less than 50 seconds into the descent. The second zone is for aborts occurring greater than 50 seconds into the descent but with an altitude greater than 25 000 ft. And the third zone is altitudes below 25 000 ft. The difference between the second and third zone is only that the third zone requires a vertical rise phase whereas the second zone does not. In zone 1 a DPS abort results in DPS shutdown, a coast phase for orientation of the LM to the abort attitude, and DPS reignition. Program P70 is used for DPS aborts. In abort zone 1 onboard program P70 does not use the ascent guidance equations because of scaling problems when the DPS is throttled below 50 percent. Instead, program P40 performs the required abort burn with external ΔV guidance (P30) to achieve the required velocity. Since external ΔV guidance is used, no position control is maintained and the 60 000 ft insertion altitude is not achieved. Program P71 is used for APS aborts. A recent onboard program change (ref. 7) has revised P71 to make it function like P70. For APS aborts in abort zone 1, the DPS is shut down, the LM is oriented to the desired abort attitude, and the APS is ignited using Program P42 and external ΔV guidance. In abort zone 1 if an abort stage is used, then a short APS fire-in-the-hole is required prior to orientation to the desired attitude in order to avoid collision with the descent stage.

Prior to recent implementation changes (ref. 1) which redefined the boundary of abort zone 1 and introduced jerk limiting (ref. 4) into the ascent guidance, abort zone 1 included the first 150 seconds into the descent, and ascent guidance with no position control was employed for both APS and DPS aborts (ref. 5). Results shown in this note for the situation where the DPS is shutdown and the LM is reoriented do not simulate external ΔV guidance of P30 but rather the implementation using the ascent guidance of P70 and P71. However, there is little difference between the two guidance techniques since both result in a near-constant attitude maneuver.

Characteristics of the abort insertion conditions for the current PGNCs implementation are shown in figure 10. Insertion altitude and attitude profiles are shown for $t_a < 200$ seconds.

5.3 Effects of Changes in Abort Targeting

The effect of changes in insertion target conditions upon insertion attitude is shown in figure 11. Insertion attitudes for the jerk limited PGNCs with DPS always at FTP is indicated for insertion velocities of 5510 fps and 5551 fps. The 5551-fps insertion velocity corresponds to insertion at pericynthion of a 60 000-ft by 60-n. mi. altitude orbit. With the larger target velocity, the insertion attitude angle, θ_β , was slightly less negative. The initial $t_{go} = 4$ seconds occurred at $t_a = 33$ seconds for 5510-fps insertion velocity and at slightly less than $t_a = 26$ seconds for 5551-fps insertion velocity. Thus an increased target velocity improves the burnout attitude, θ_β , and decreases the time of abort at which the 4-second t_{go} boundary occurs. Burnout attitudes for the 5551-fps insertion velocity are still unacceptable because if $26 < t_a < 40$, then $-116^\circ < \theta_\beta < -40^\circ$.

6.0 ELIMINATION OF DPS SHUTDOWN DURING DPS ABORTS

The current implementation is quite acceptable for APS aborts since there is no objection to a 30-second delay prior to staging and APS ignition in order for the LM to reach the desired abort attitude when $t_a < 50$ seconds. However, there are several reasons to question this procedure for DPS aborts. First, DPS shutdown and reignition shortly thereafter is questionable because of the possibility the DPS will fail to reignite due to freezeups of the fuel in the heat exchanger. Secondly,

it is inherently undesirable in an abort situation to shut down a propulsion system that has not failed.

6.1 Effects of the Use of DPS Throttling Capability

The question arises whether use of the DPS throttling capability would allow the DPS to always remain on during early aborts. The reason early APS and DPS aborts can be described as having such similar characteristics is that in each case the thrust-to-weight ratios of the staged and unstaged LM are almost identical if the DPS is at FTP. If the DPS is throttled, this is no longer true and abort characteristics would not be similar. The principal difficulty in use of the DPS throttling capability is that software change is required for the PGNCS abort guidance program (P70) to be capable of giving a solution for thrust accelerations below 5 ft/sec^2 (throttling below 50 percent). This restriction is present because of an onboard computer scaling problem. In this note it is assumed that if the sensed acceleration is below the threshold, simulated FTP acceleration levels are used by the onboard computer to calculate the desired thrust acceleration direction. It was also assumed that minimum (10 percent) thrust was maintained for the first 18 seconds of the abort since the desired attitude may be 180° from the current attitude and the maximum turning rate is 10 deg/sec .

Effects of throttling the DPS to 10 percent thrust for the first 18 seconds of an abort are shown in figure 12. In the jerk-limited case with minimum thrust, the insertion altitude stays near 50 000 ft for $33 < t_a < 150 \text{ sec}$. For $t_a > 150 \text{ seconds}$ the insertion altitude increases, reaching 60 000 ft for $t_a \sim 250 \text{ sec}$. The minimum insertion attitude for the minimum thrust case is only -12° below the local horizontal. Thus use of DPS throttling improves the burnout attitude for $33 < t_a < 50 \text{ sec}$.

Figure 13 shows the effect of increased insertion velocity on burnout attitude when minimum thrust is used for the first 18 seconds of the abort. The 4-second t_{go} limit occurs at $t_a = 33 \text{ seconds}$ for 5510 fps insertion velocity, and the burnout attitude is only -14° . When the target velocity is increased to 5551 fps, an abort at the end of the trim phase ($t_a = 26 \text{ seconds}$) results in a burnout attitude of -29° . Thus, if the standard insertion orbit is changed from a 60 000-ft by 30-n. mi. to a 60 000-ft by 60-n. mi. altitude orbit, acceptable insertion conditions can be achieved for $26 < t_a < 50 \text{ seconds}$ if the DPS is throttled down to minimum thrust for the first 18 seconds of the abort.

6.2 Implementation for DPS Aborts

Two alternate implementation plans were considered for DPS aborts. The first implementation employs DPS throttling whereas the second does not.

The first implementation may be summed up as requiring

1. Jerk limiting guidance.
2. Increase apocynthion of insertion orbit of 60 n. mi. or higher.
3. DPS shutdown if an abort occurs during the 26-second trim phase.
4. DPS throttled to minimum thrust for first 18 seconds of an abort if the abort occurs between 26 and 50 seconds into the descent.
5. The same procedures as APS aborts for DPS aborts after 50 seconds into the descent.

This implementation is summarized in figure 14.

If the 26-second trim phase is reduced, then in order to use the proposed DPS abort implementation, the desired insertion velocity must be increased to be sure that the initial $t_{go} > 4$ seconds for aborts at the beginning of the braking phase. Results indicate for a 10-second trim phase the target apocynthion altitude would have to be 80 n. mi.

Since available propellant is not a critical factor for early DPS aborts, an alternative to the use of DPS throttling would be to require the LM to be steered to the retrograde attitude ($\theta = \pm 180^\circ$) and maintain it until the time from DPS ignition is 50 seconds, then to begin steering toward the standard abort targets with jerk limiting guidance. Modifications to P70 to cause the LM to continue in the retrograde attitude until good abort conditions are achieved would probably require fewer program changes than would modifying the ascent guidance to operate with simulated FTP DPS thrust levels while the DPS is at minimum thrust.

7.0 GUIDANCE AND PROCEDURE ALTERNATIVES

In order to summarize the effects of aborting with the various guidance modes and operational procedures with the propulsion systems, the effects of six guidance and procedure techniques have been described for aborts during the first 200 seconds of powered descent:

1. Guidance with position control and propulsion system always operative (DPS at FTP).
2. Guidance with jerk limiting and propulsive system always operative (DPS at FTP).
3. Guidance with no position control and propulsion system always operative (DPS at FTP).
4. Guidance with no position control and propulsive system operation shut down for the LM to orient to the desired abort attitude prior to abort burn.
5. Guidance with no position control and the DPS throttled to 10 percent thrust during first 18 seconds of abort.
6. Guidance with jerk limiting and the DPS throttled to 10 percent thrust during first 18 seconds of abort.

A summary of the insertion altitude and attitude profiles for these techniques are shown in figures 15 and 16, respectively, for DPS aborts. When both the procedure of DPS shutdown while the LM is in a safe orbit and the procedure of continued retrograde burn with the DPS are included with the six guidance and procedure techniques listed above, then we have all of the alternatives for performance of early LM aborts from powered descent considered in this note.

In order to summarize the various alternatives for early aborts, five abort regions can be defined for the first 200 seconds into the descent.

1. Region A is defined as the trim phase where $0 < t_a < 26$ seconds.
2. Region B is from the beginning of the braking phase where the DPS goes to FTP to $t_a = 50$ seconds except for the case where position control is used. In that case Region B is defined as $26 < t_a < 60$ seconds. Region B with position control is characterized by marginal achievement of insertion conditions, insertion altitude variations, and extremely unacceptable pitch attitude profiles. (See figures 2 and 3.) Since the current implementation defines the boundary between abort zone 1 and 2 at $t_a = 50$ seconds, the nominal maximum limit for region B was chosen at $t_a = 50$ seconds.
3. Region C is defined by 50 (or 60) $< t_a < 110$ seconds. The maximum limit of $t_a = 110$ seconds was chosen because aborts with position

control in this region retain the period of attitude hold at $\theta = 90^\circ$ but no longer retain attitude hold at $\theta = -90^\circ$ as in region B (fig. 3).

4. Region D is defined by $110 < t_a < 150$ seconds.

5. Region E is for $t_a > 150$ seconds. The boundary between regions D and E at $t_a = 150$ seconds was chosen because this was the boundary for abort zone 1 for the former implementation, prior to approval of PCR 70 (ref. 1).

A summary of the effects of the various alternative procedures considered in this study is shown in figure 17, which includes the division of early aborts into five regions. Both the current and former implementation is illustrated as well as two proposals to eliminate the necessity to shut down the DPS for $t_a < 50$ seconds.

8.0 CONCLUSIONS

An investigation has been conducted into the characteristics of LM aborts during the first 200 seconds of powered descent which are controlled by the PGNCs. Not only were the characteristics due to the current implementation and procedures investigated but also the effects of other guidance modes and uses of available propulsion systems. This study includes the effects of the recent implementation changes which redefined the abort zones and introduced jerk limiting into the ascent guidance equations. Effects of throttling the DPS during DPS aborts were investigated.

Results indicate that the present implementation for APS aborts is adequate. For APS aborts during the first 50 seconds of the descent the DPS is shut down, the LM oriented to abort attitude, and APS abort burn is performed with guidance having no position control. There is no difficulty with this delay of the abort burn. Minimum insertion altitudes would be about 49 000 ft. For APS aborts after 50 seconds into the descent, there is no delay in performing the abort maneuver. Jerk limiting in the guidance assures that the insertion altitude increases from a minimum of 52 000 ft for aborts at 50 seconds to the nominal 60 000 ft for aborts about 150 seconds into the descent. Attitude profiles for these aborts are considered to be quite acceptable. The maximum attitude of the +X-body axis at insertion is about 30° below the local horizontal.

DPS aborts have similar characteristics to APS aborts. However, the implementation for DPS aborts is inadequate in that for aborts during the first 50 seconds of the descent the DPS is shutdown, the LM is

reoriented to abort attitude, and the DPS is reignited. It is not desirable in an abort situation to shut down an operating propulsion system that has not failed. (In fact, such operation with the DPS could cause fuel to freeze in the heat exchanger, in which case the DPS would fail to reignite.) Two methods to eliminate the requirement of DPS shutdown were found. One method uses the DPS throttling capability. DPS throttling to minimum thrust for the first 18 seconds of the abort burn can be used for aborts occurring between the end of the trim phase and 50 seconds into the descent, provided the desired insertion velocity is at least 5551 fps. The second method to eliminate DPS shutdowns requires the continuation of the DPS burn in the retrograde attitude until the DPS burn time is 50 seconds, at which time steering toward the desired target conditions is initiated. Both methods require onboard software changes.

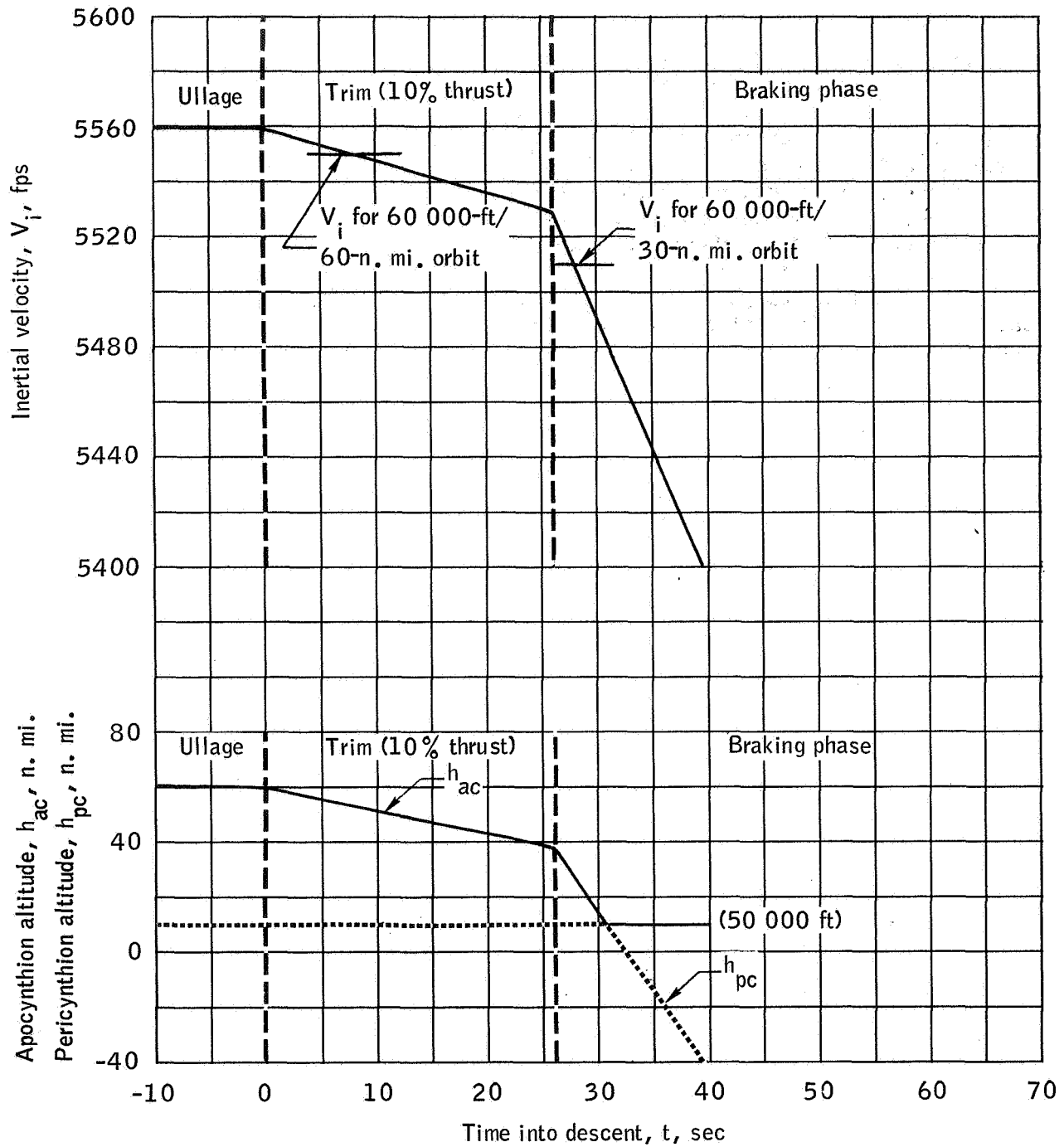


Figure 1.- LM descent trajectory parameters during early descent.

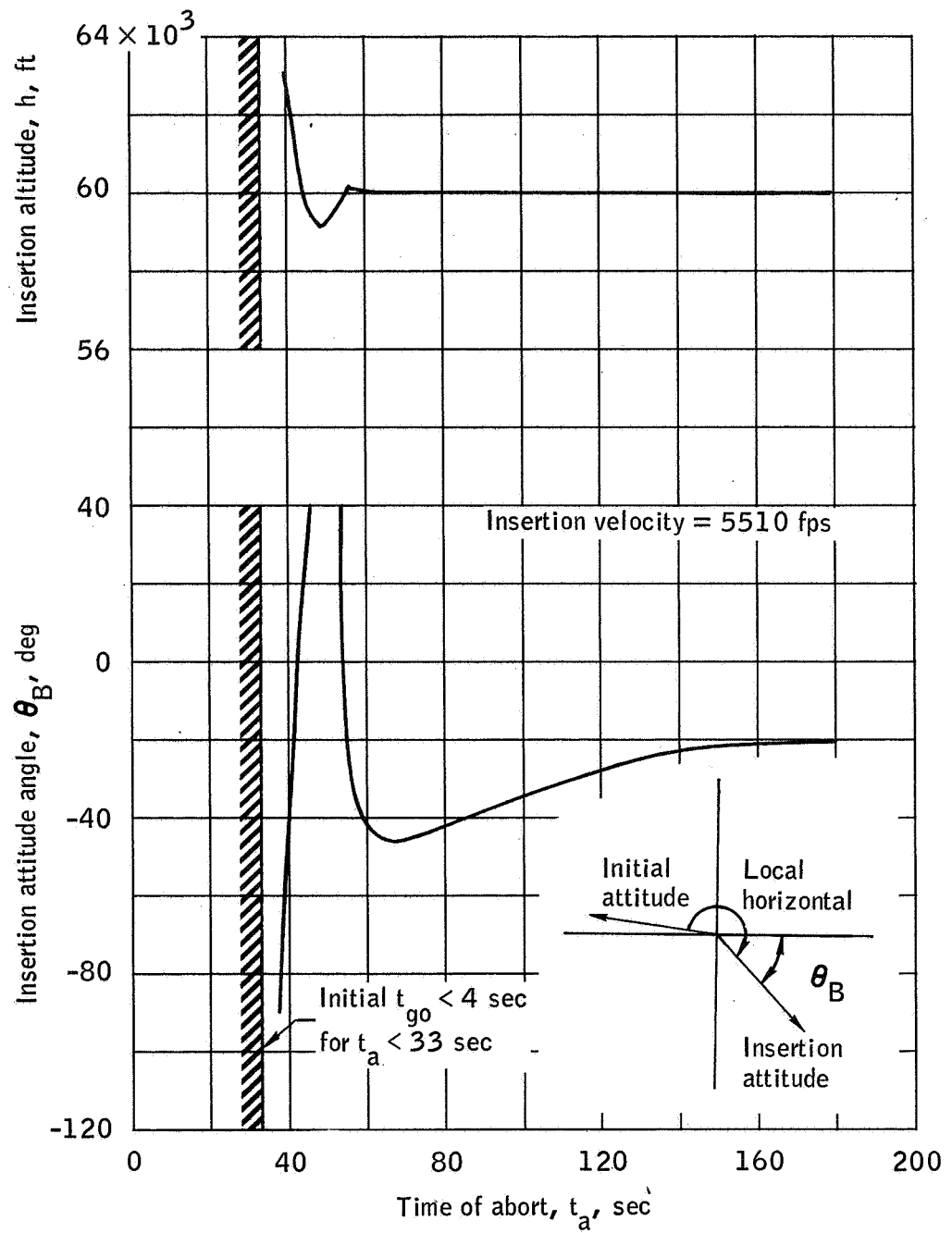


Figure 2.- Insertion altitude and attitude profiles for early LM aborts using position control.

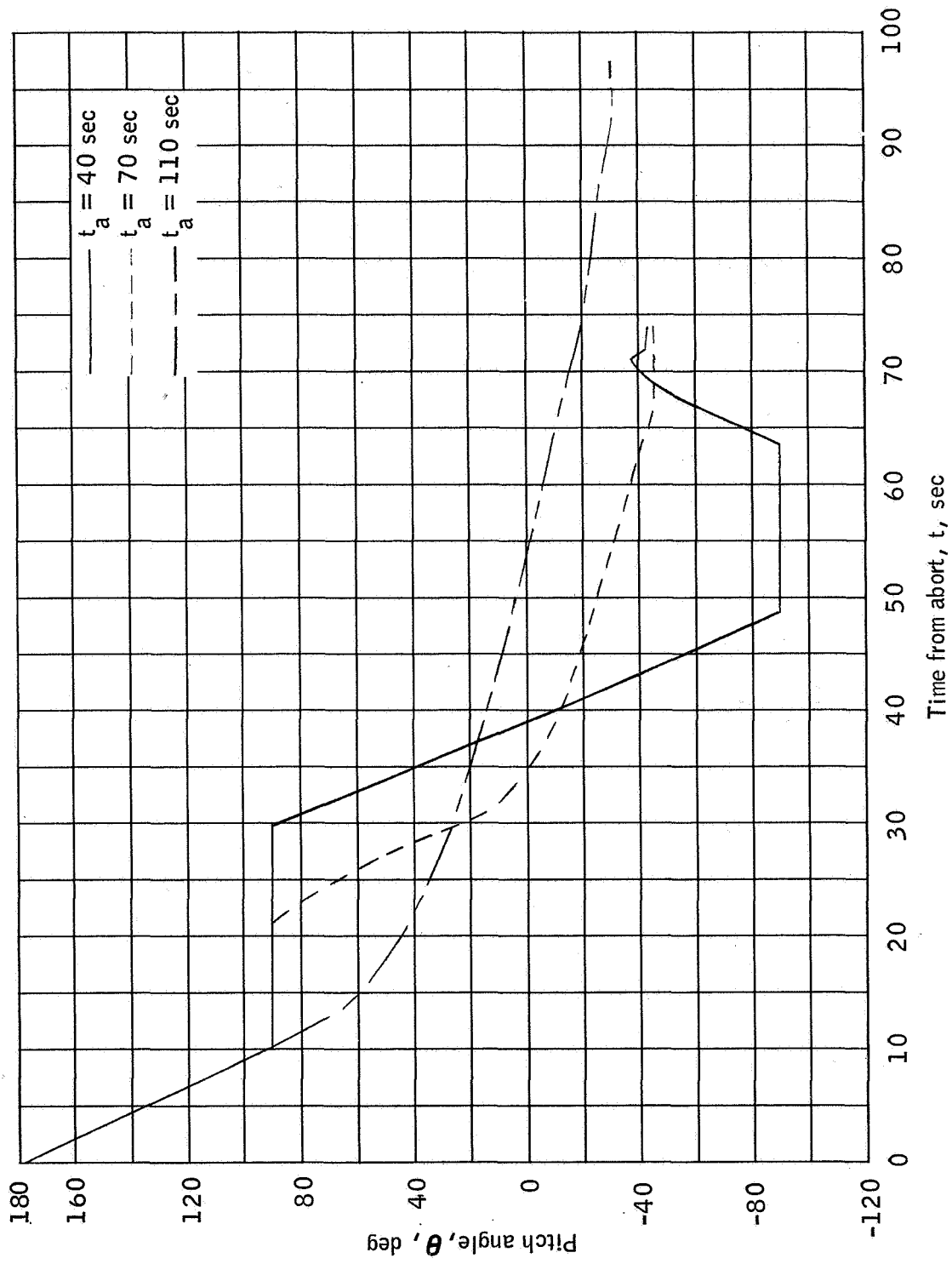


Figure 3. - Abort attitude profiles for aborts at various abort times using position control.

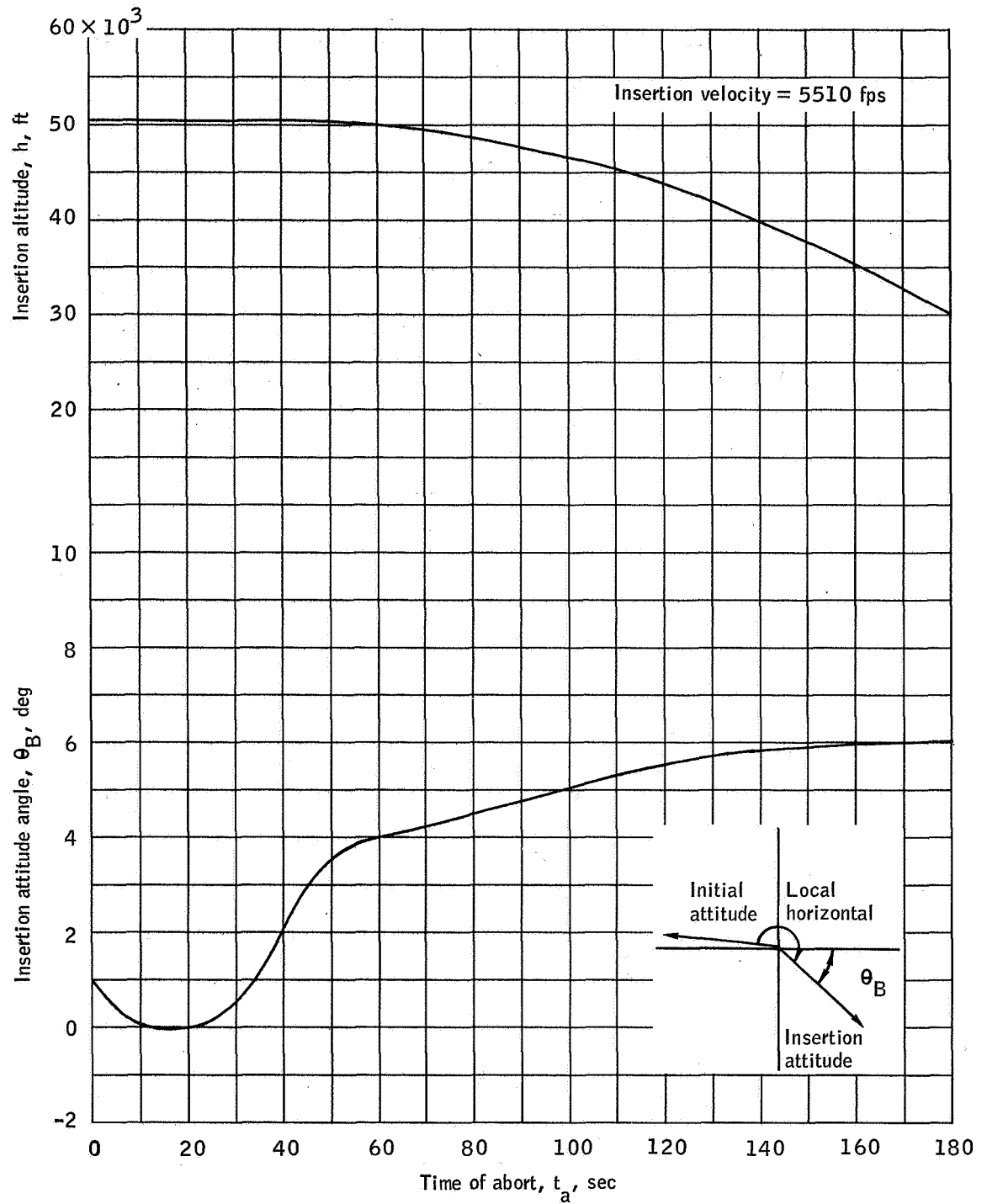


Figure 4.- Insertion altitude and attitude profile with no position control and with 30 second delay prior to abort burn.

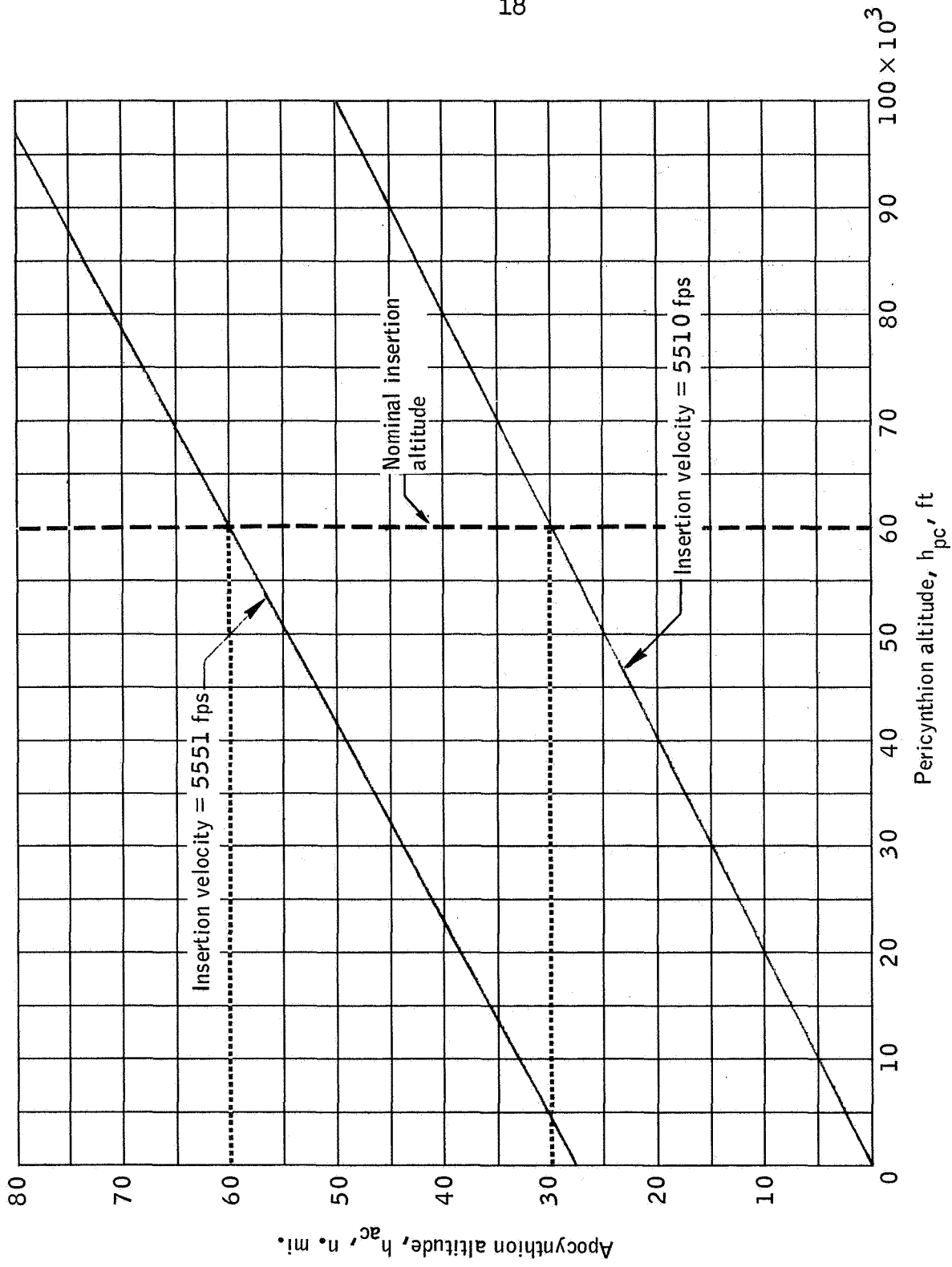


Figure 5.- Apocynthion altitude versus pericynthion altitude for constant insertion velocity.

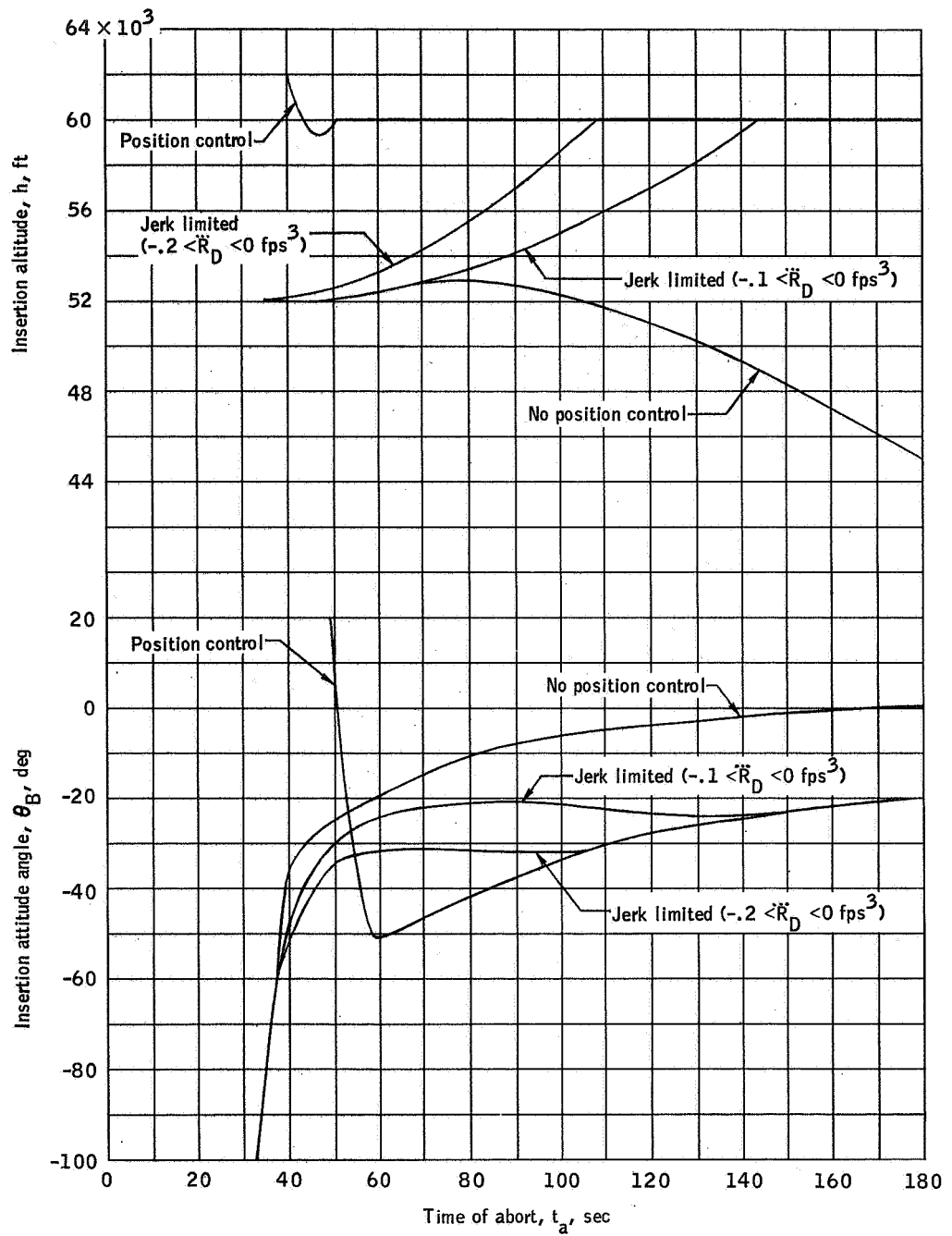


Figure 6.- Effect of guidance with jerk limiting.

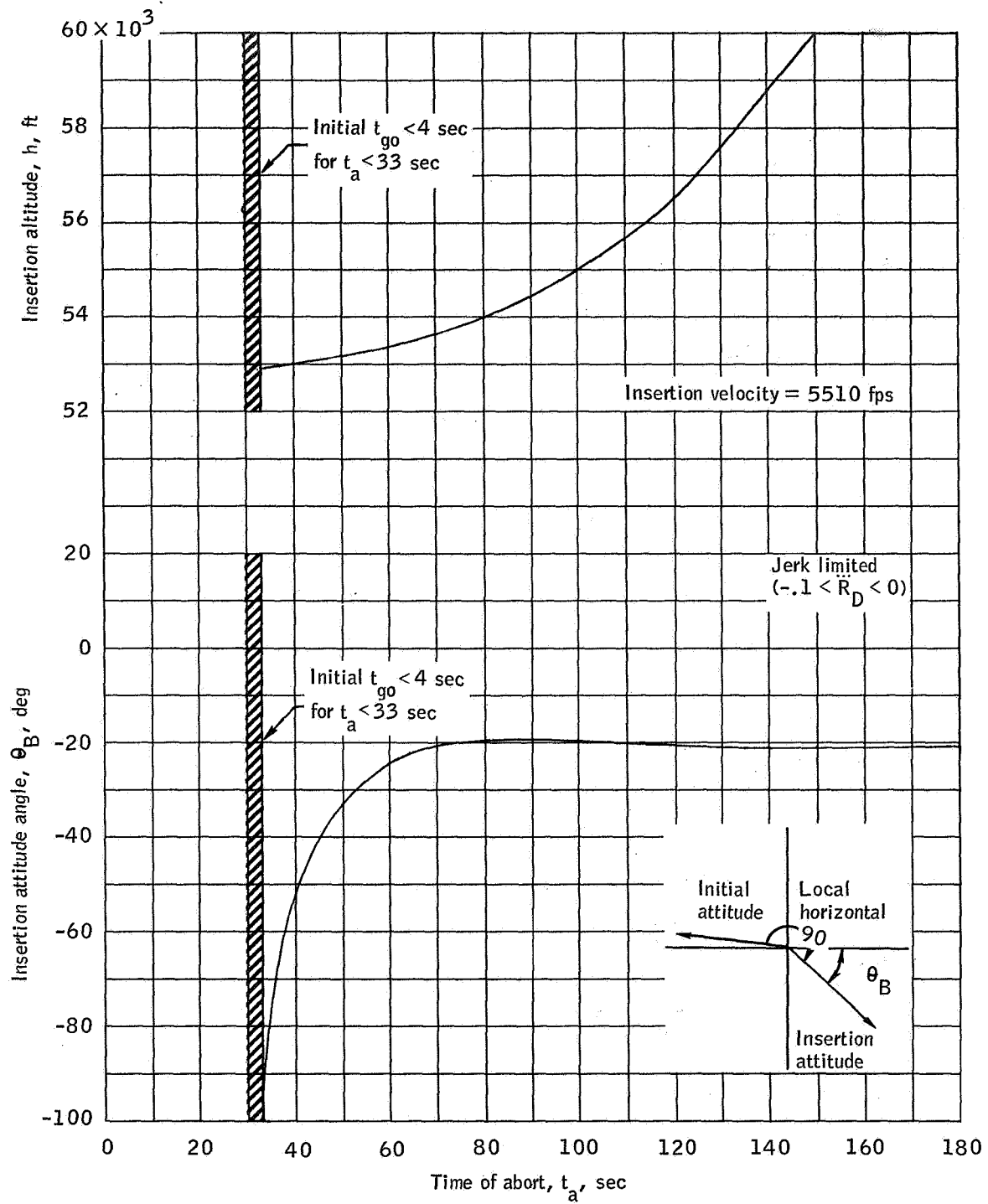


Figure 7.- Insertion altitude and attitude profile when jerk limiting guidance is used.

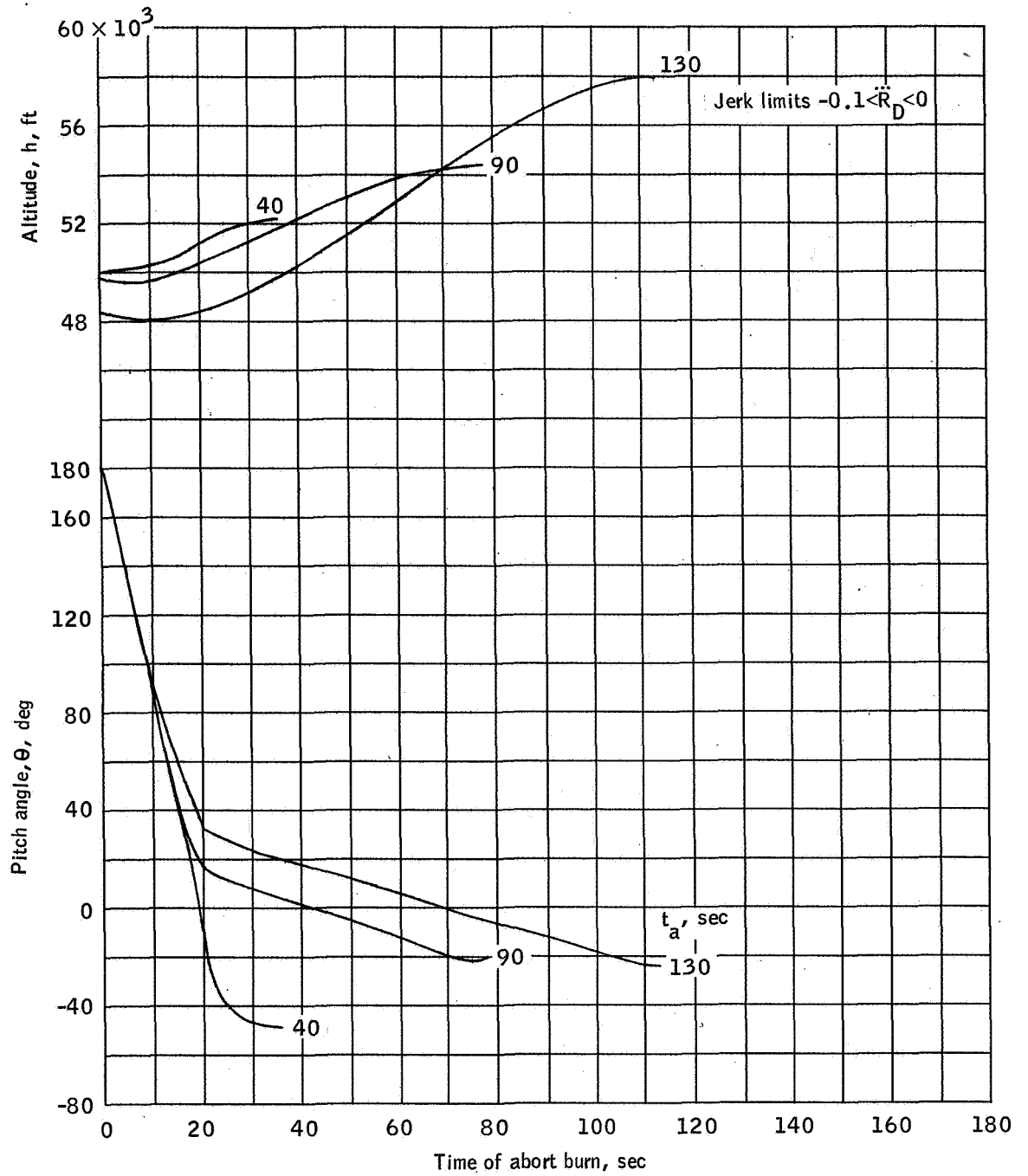


Figure 8.- Abort profiles when jerk limiting guidance is used.

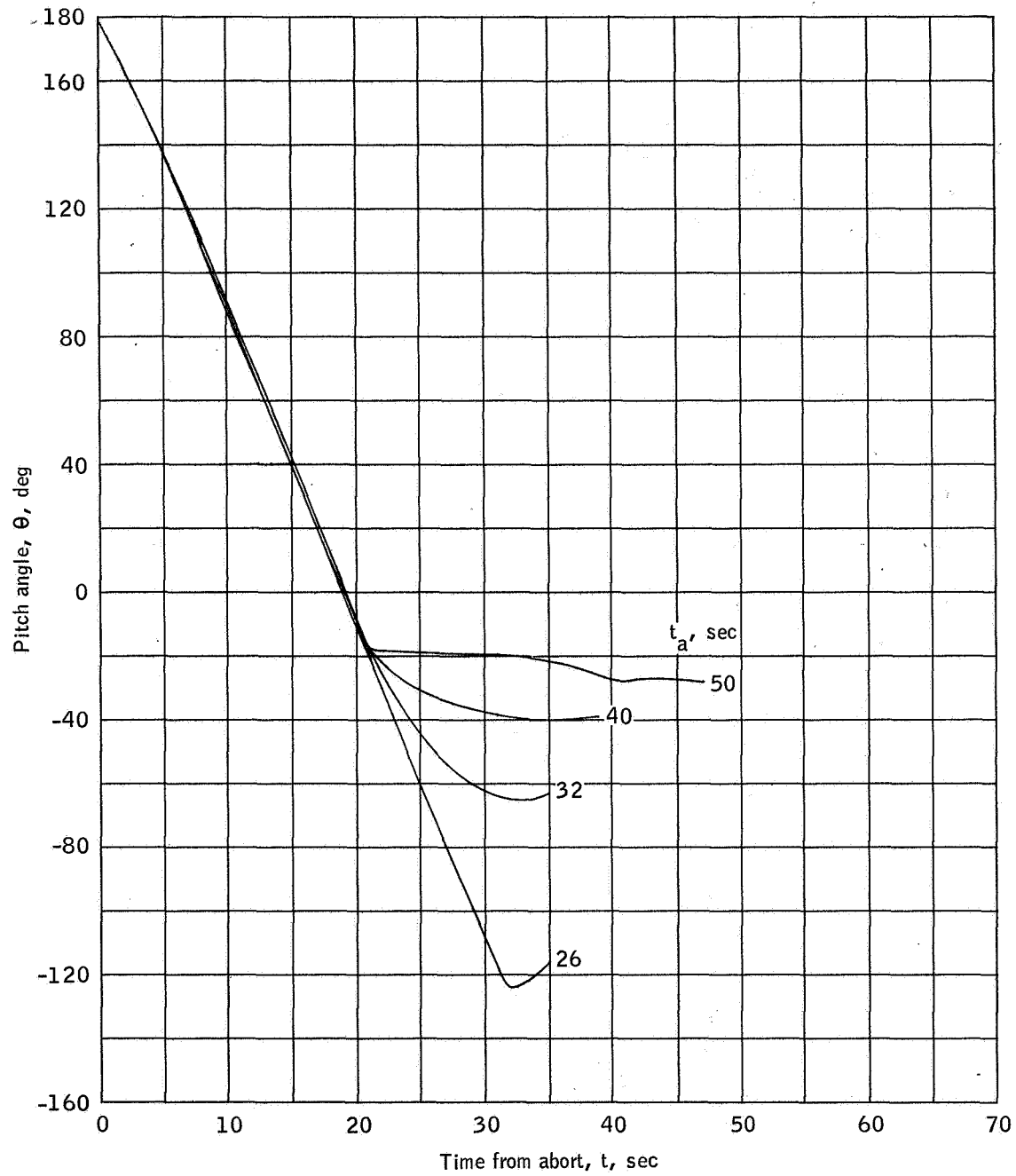


Figure 9.- LM abort profiles for jerk limited PGNCs for aborts between 26 and 50 seconds into descent.

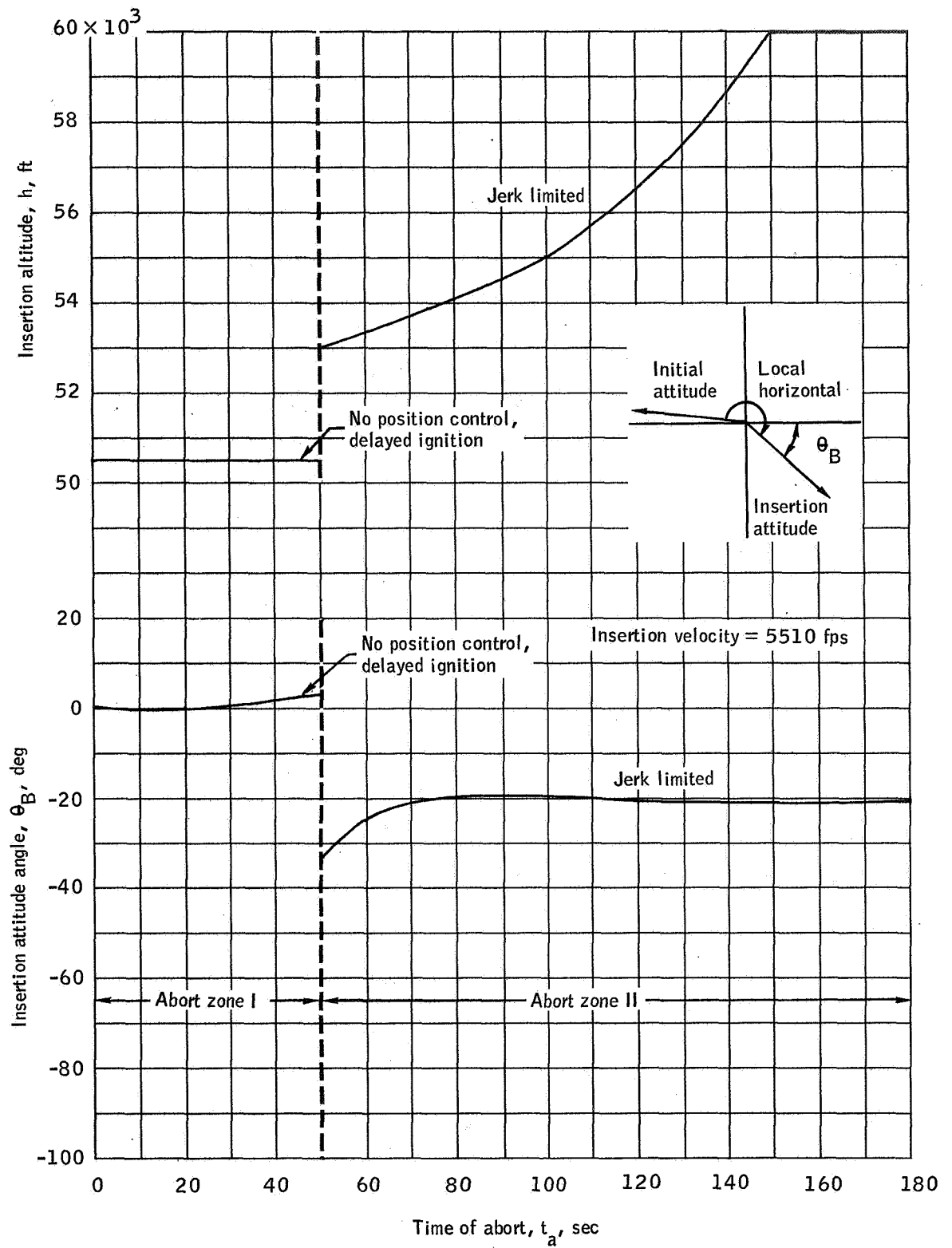


Figure 10.- Current PGNCs implementation.

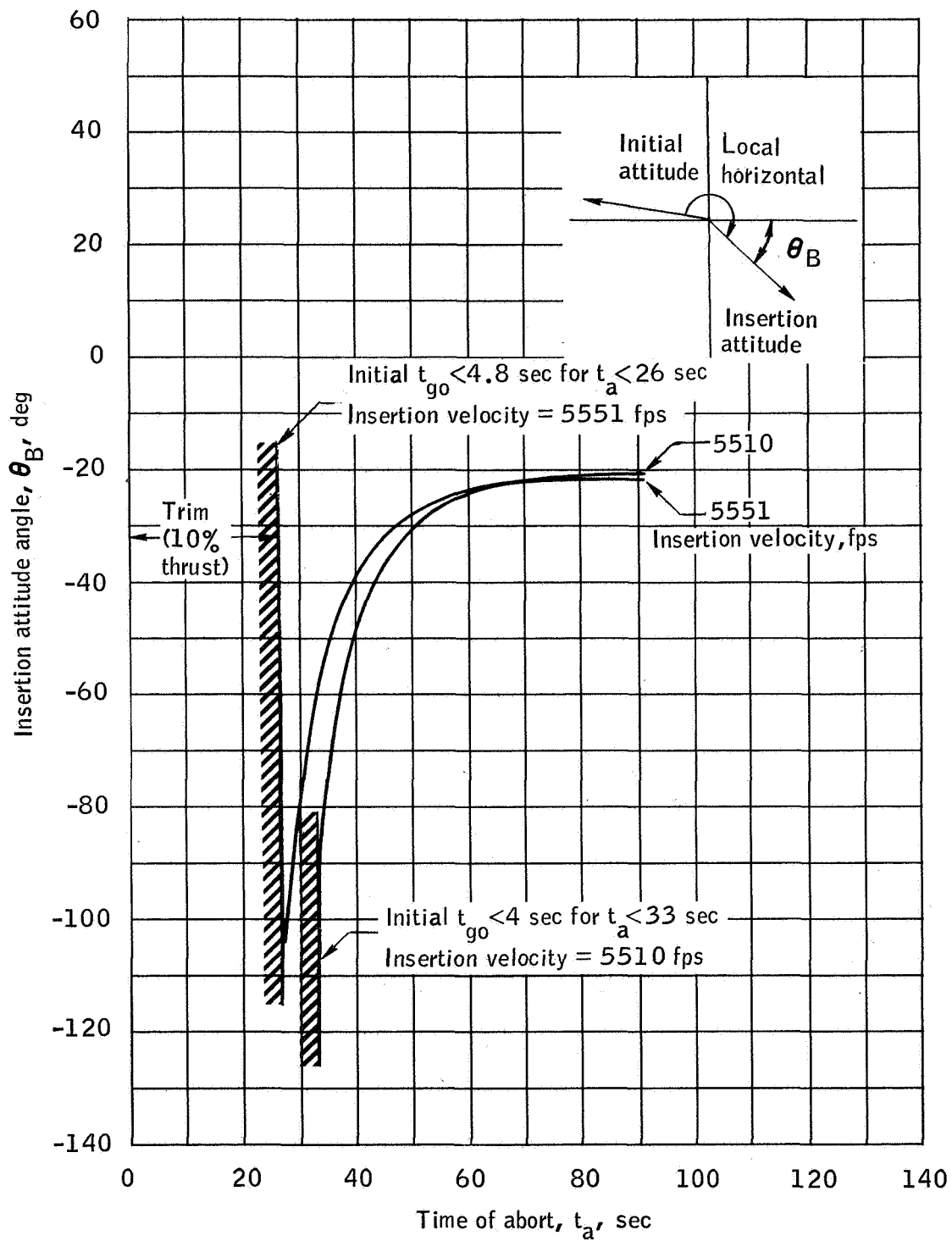


Figure 11.- Effect of target changes upon insertion attitude when jerk limited guidance is used.

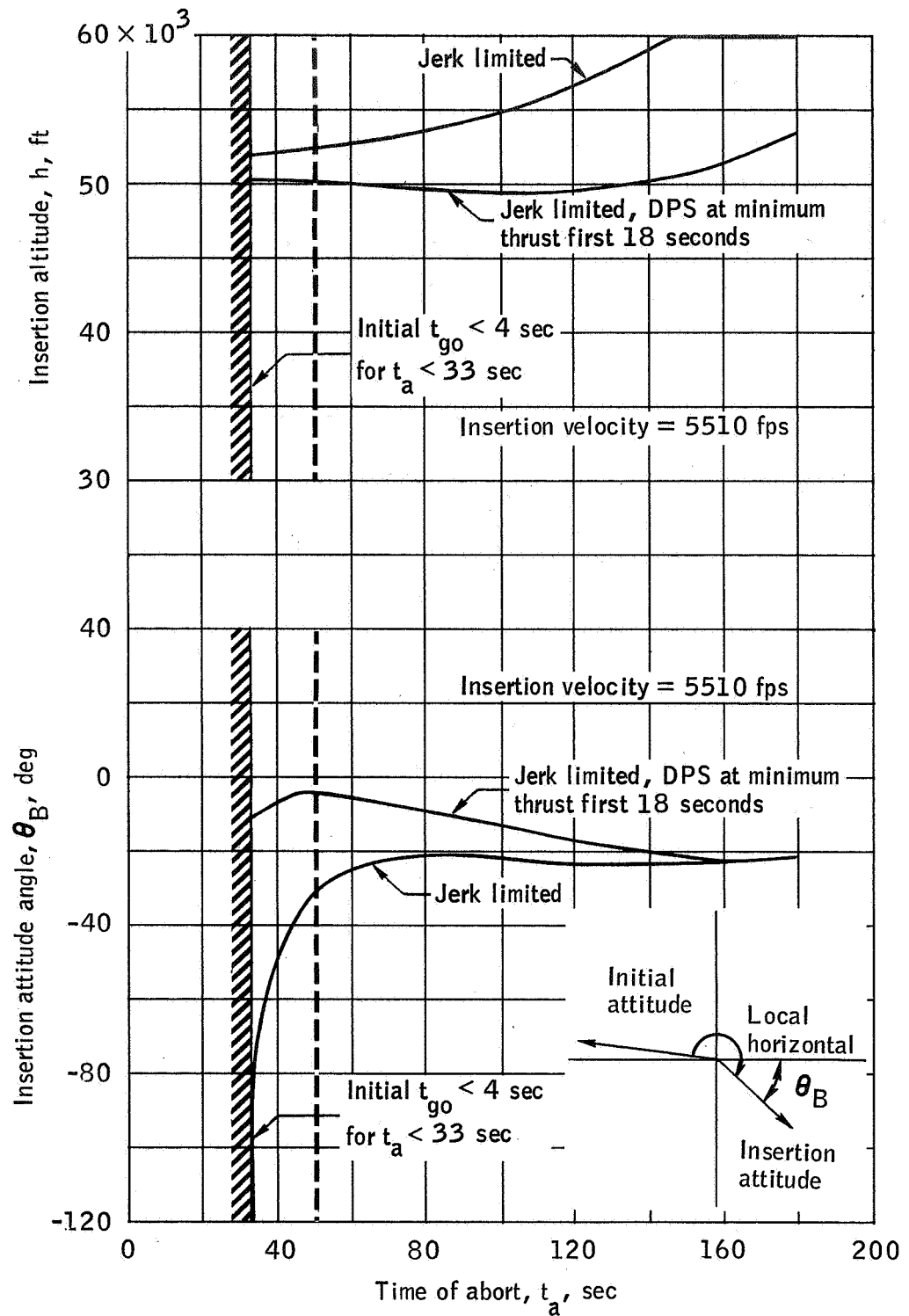


Figure 12.- Effects of throttling DPS to 10 percent thrust for first 18 seconds of abort.

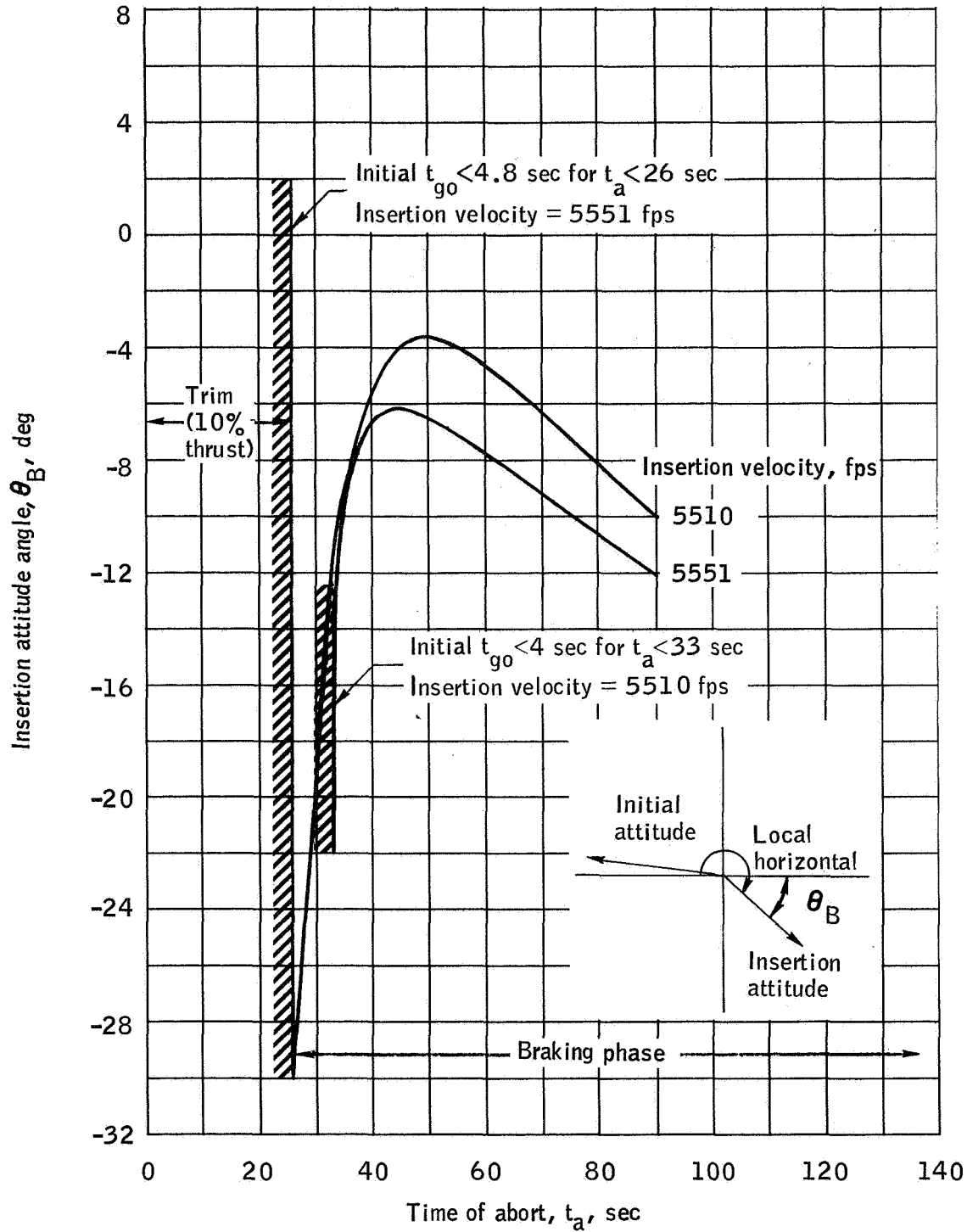


Figure 13.- Effects of DPS throttling with target variation (jerk limited).

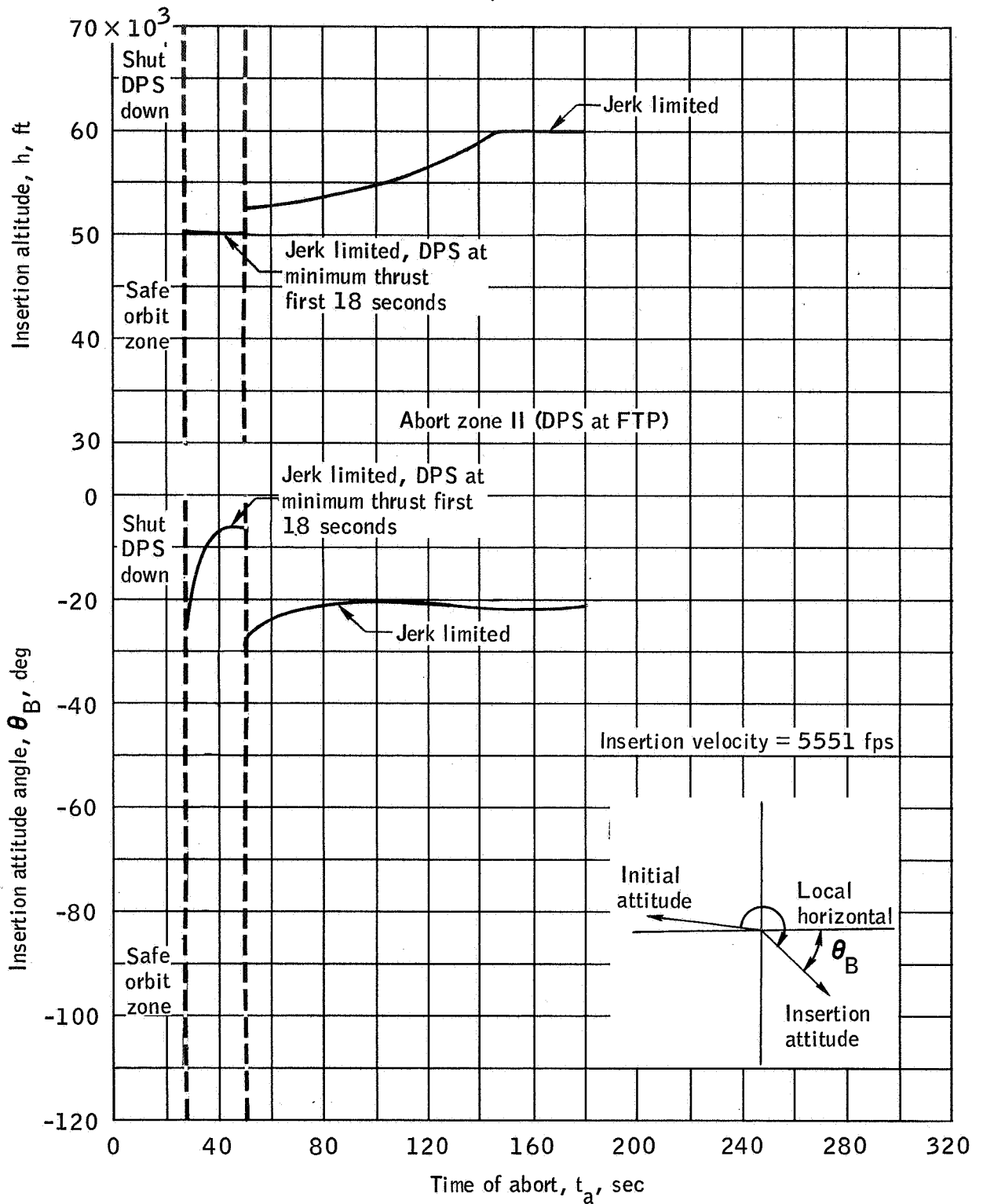


Figure 14.- Implementation for DPS aborts using DPS throttling.

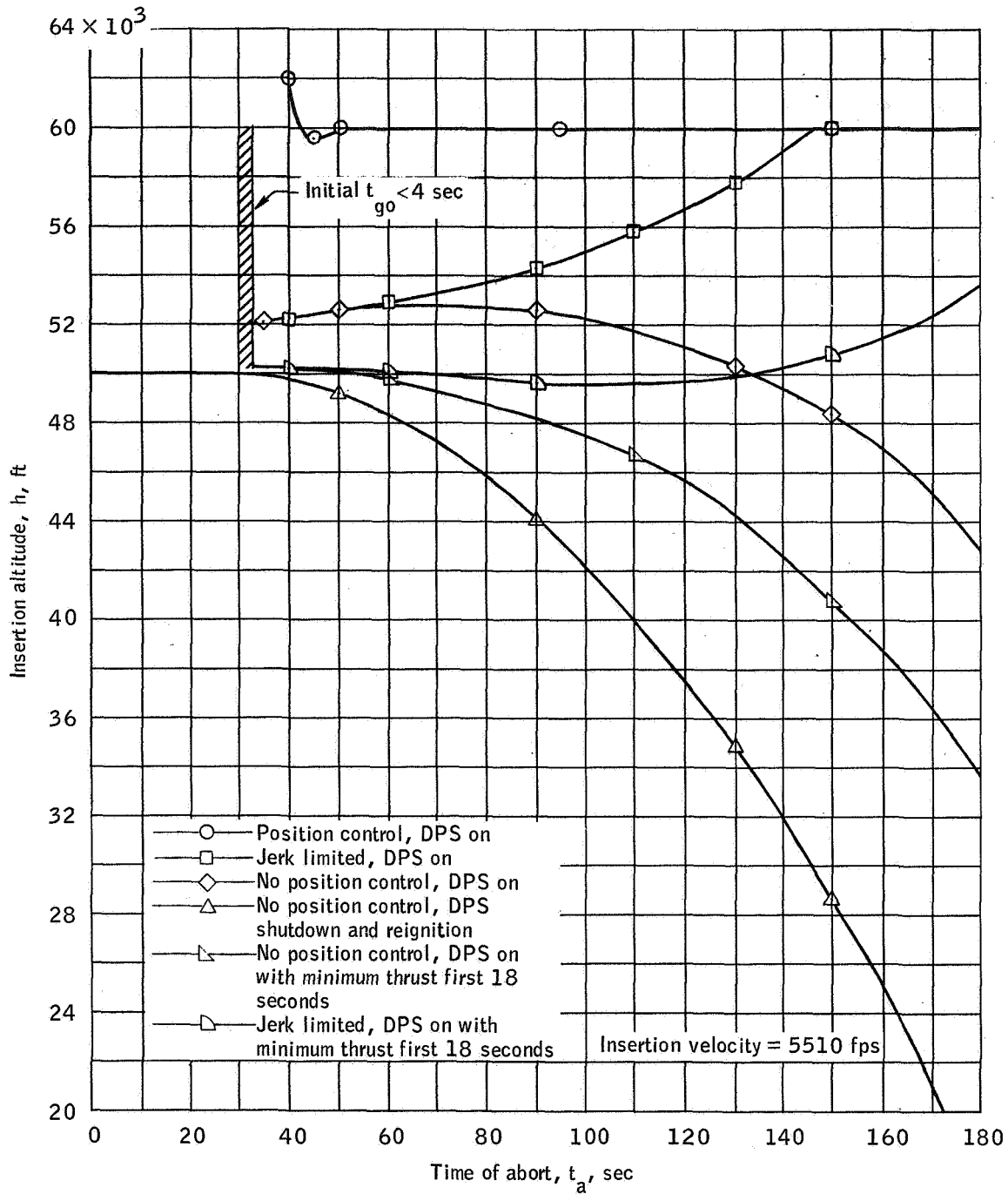


Figure 15.- Insertion altitude for early LM aborts from descent with various guidance modes which use the DPS.

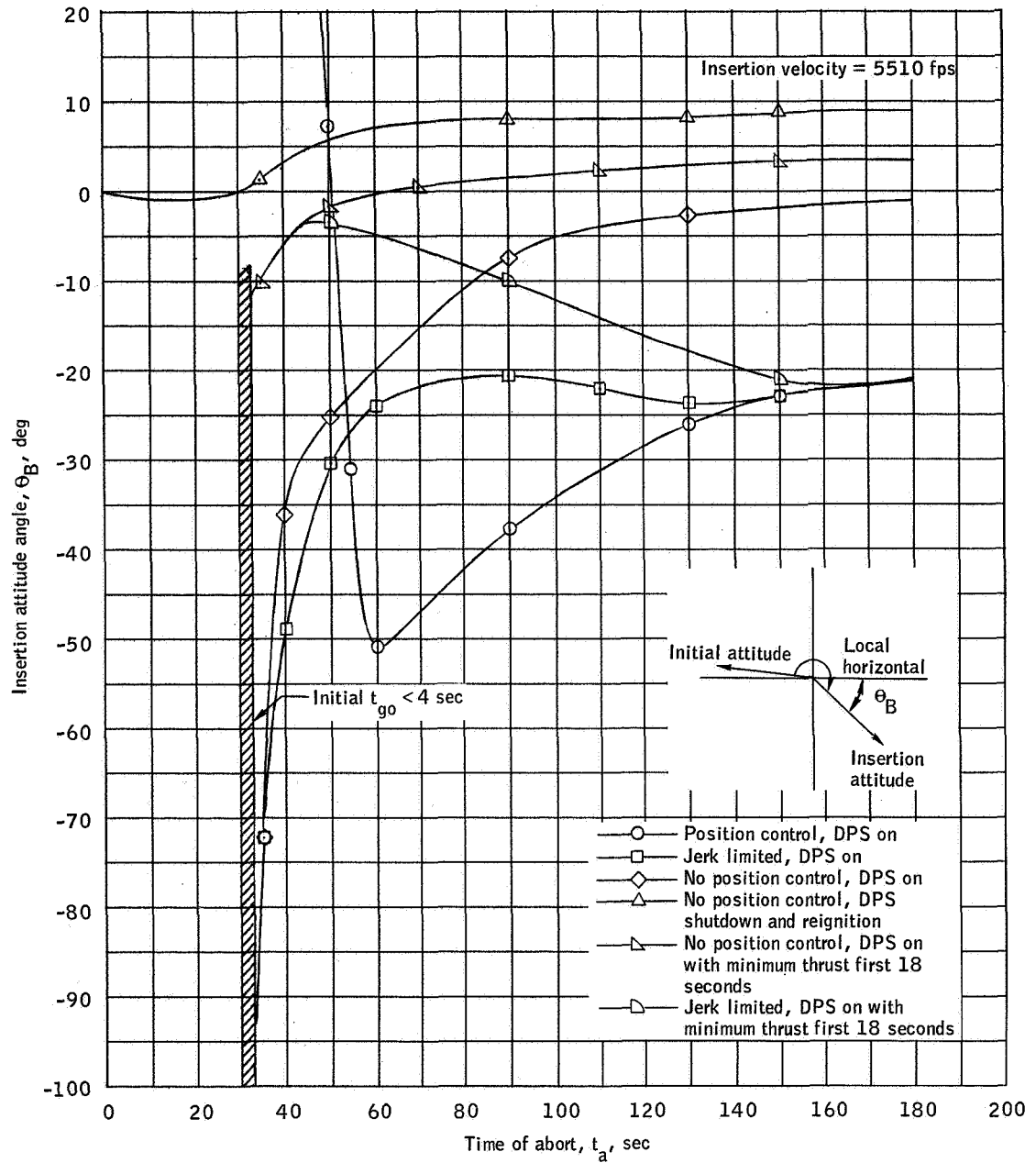


Figure 16.- Insertion attitude for early LM aborts from descent with various guidance modes which use the DPS.

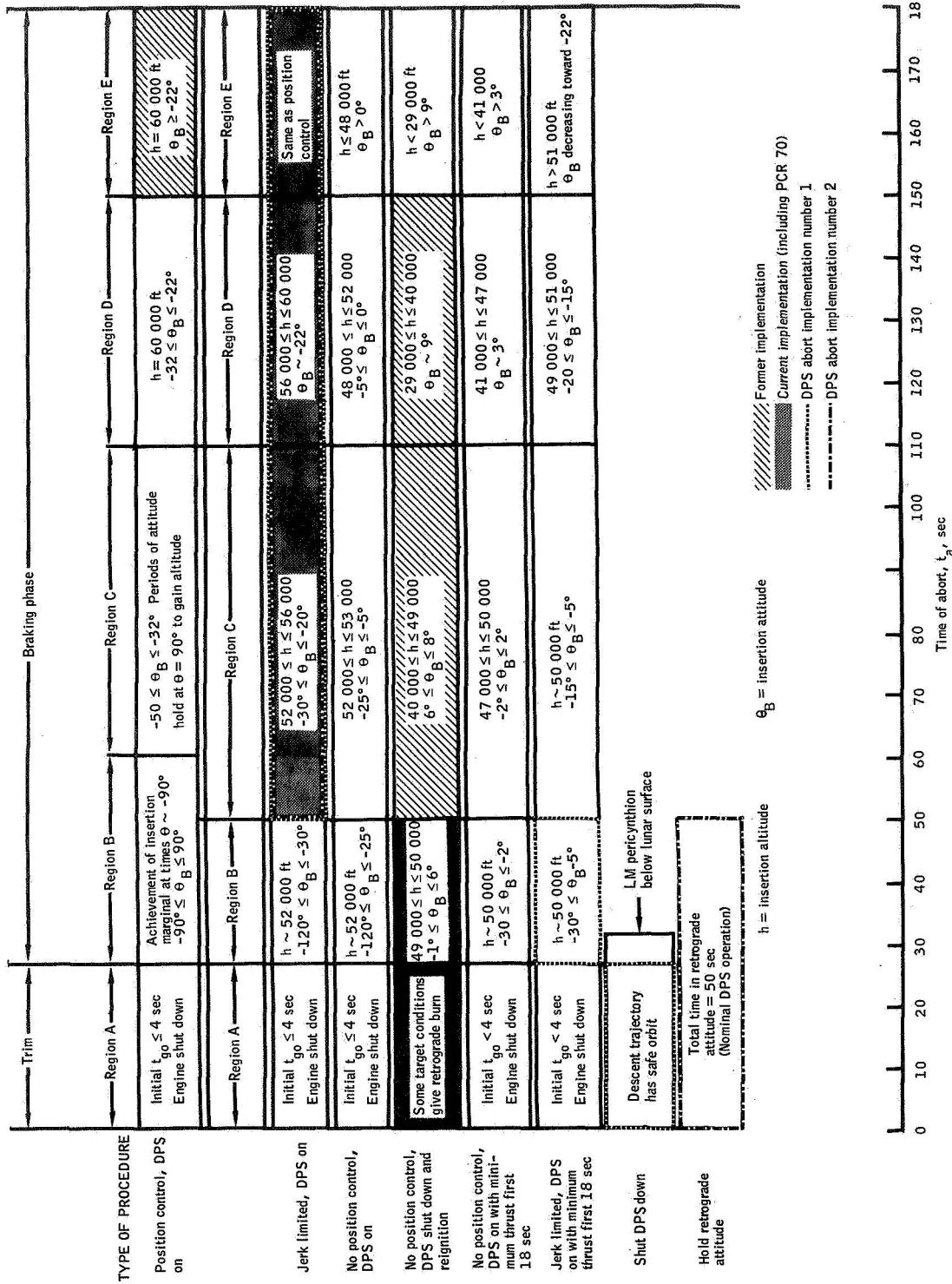


Figure 17. Guidance and procedure alternatives for early aborts from descent with the DPS.

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